NASA's ESO
Surface Deformation & Change

2022 AGU Town Hall

National Aeronautics and Space Administration

EXPLORE EARTH

Surface Deformation and Change Town Hall

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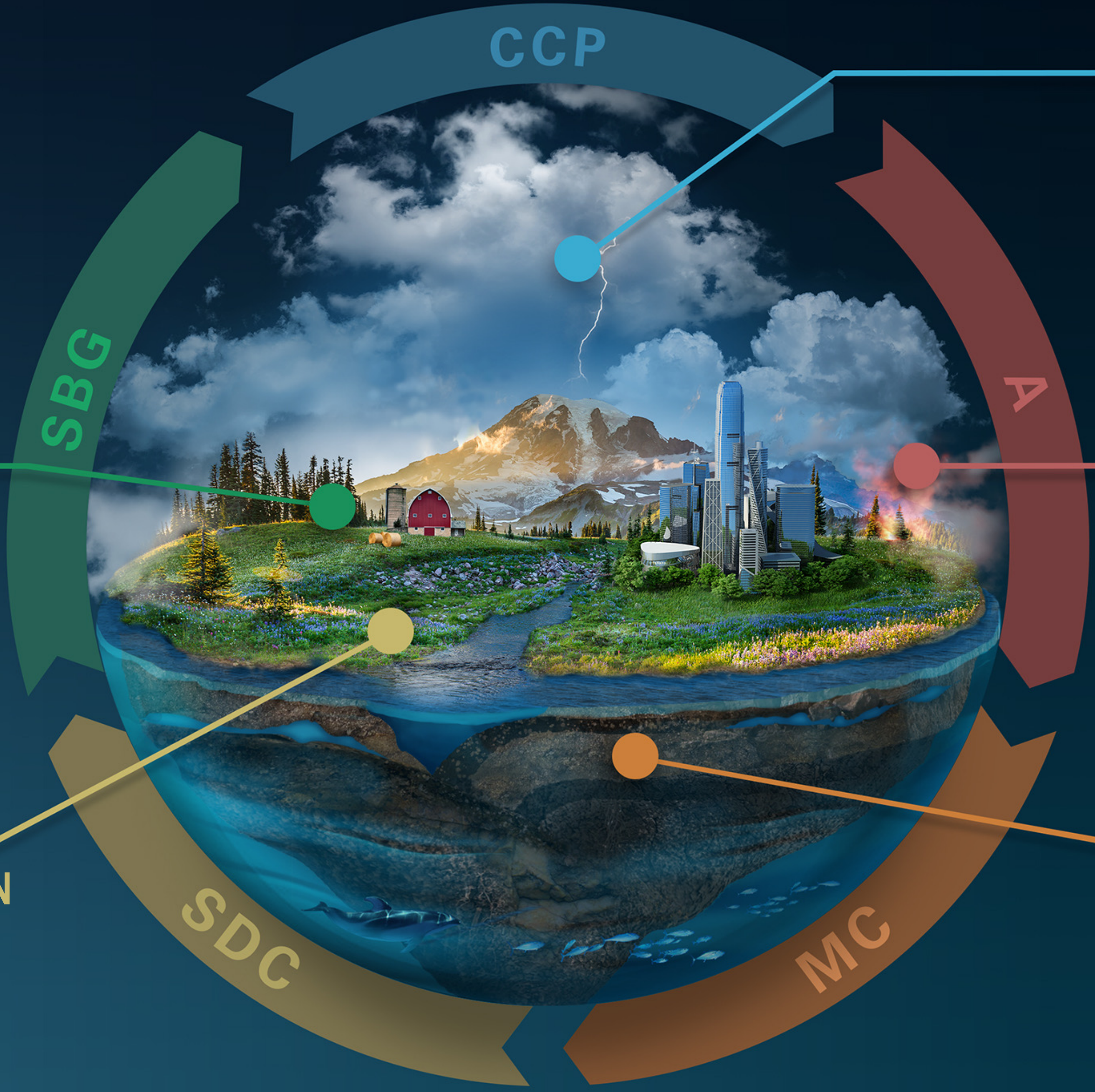
Dec. 13, 2022

EARTH SYSTEM OBSERVATORY

INTERCONNECTED
CORE MISSIONS



CLOUDS, CONVECTION AND PRECIPITATION

Water and Energy in the Atmosphere

AEROSOLS

Particles in the Atmosphere

SURFACE BIOLOGY AND GEOLOGY

Earth Surface & Ecosystems

SURFACE DEFORMATION AND CHANGE

Earth Surface Dynamics

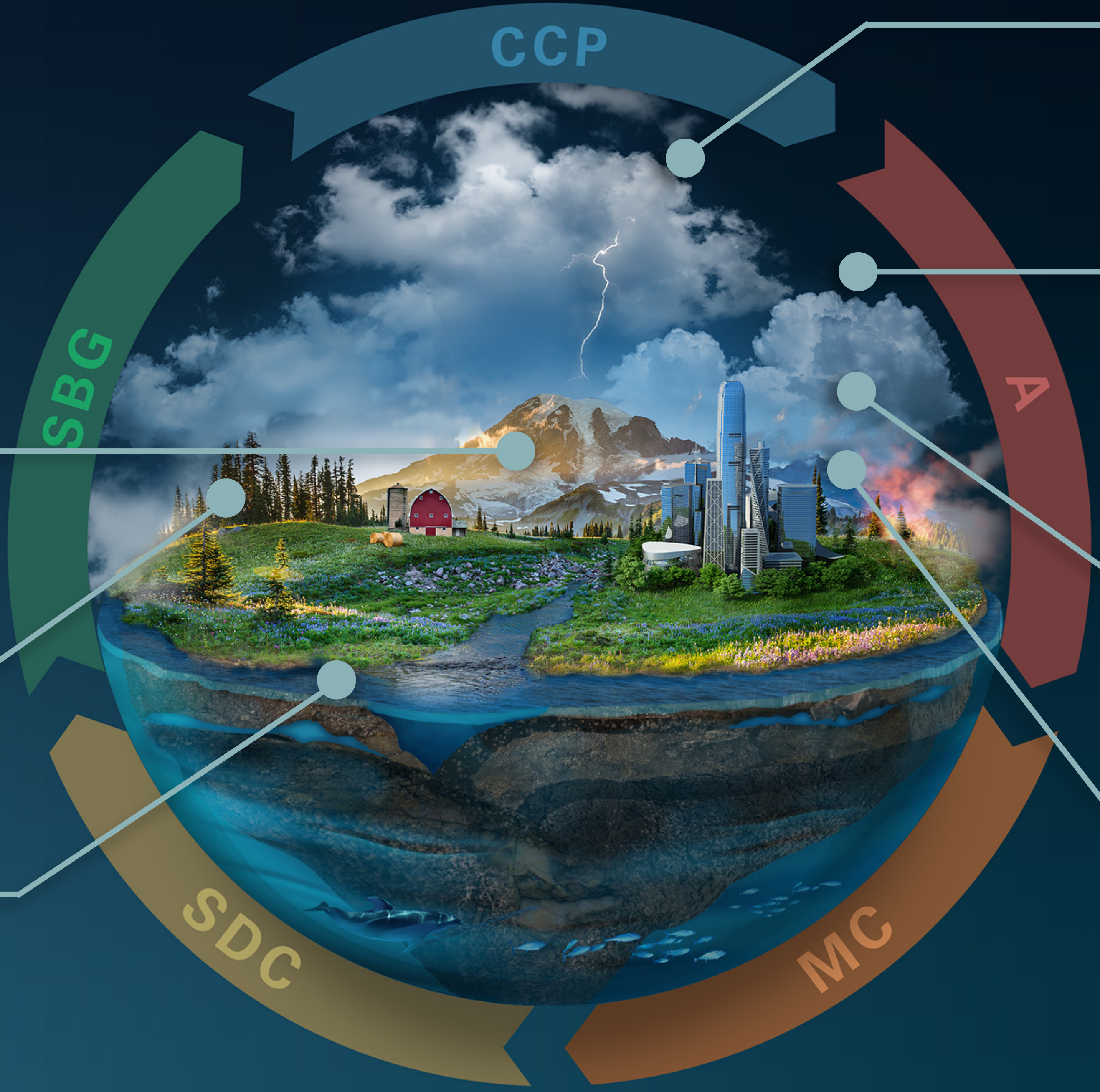
MASS CHANGE

Large-scale Mass Redistribution

EARTH SYSTEM

OBSERVATORY

INNOVATION & COMPETITION
EARTH EXPLORER MISSIONS



NASA Earth Action Strategy


NASA EARTH
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SDC Goals

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Serve stakeholders in the following Science Communities according to the SATM:

SDC Observation Goals in Decadal Survey:

- Interferometric repeat-pass SAR at sub-weekly to daily rates.
- Resolution needs ranging from 5m to 15m
- Sensitivity to height changes between 1-10 mm
- Time series measurements from 1 mm/week to 1 mm/year
- Continuous global monitoring of all land and coastal areas
- Supplement the program of record running from 2017-2027
- Provide a plan for a 10+ year mission lifetime
- Maximum cost to NASA of $500M (Phase A-F)

Explicit NASA-specified SDC Observation Goals:

- Include SAR radiometry, not only interferometry, in architectures
- Noise equivalent sigma-0 < -20 dB
- Ambiguities < -20 dB

The SDC Study

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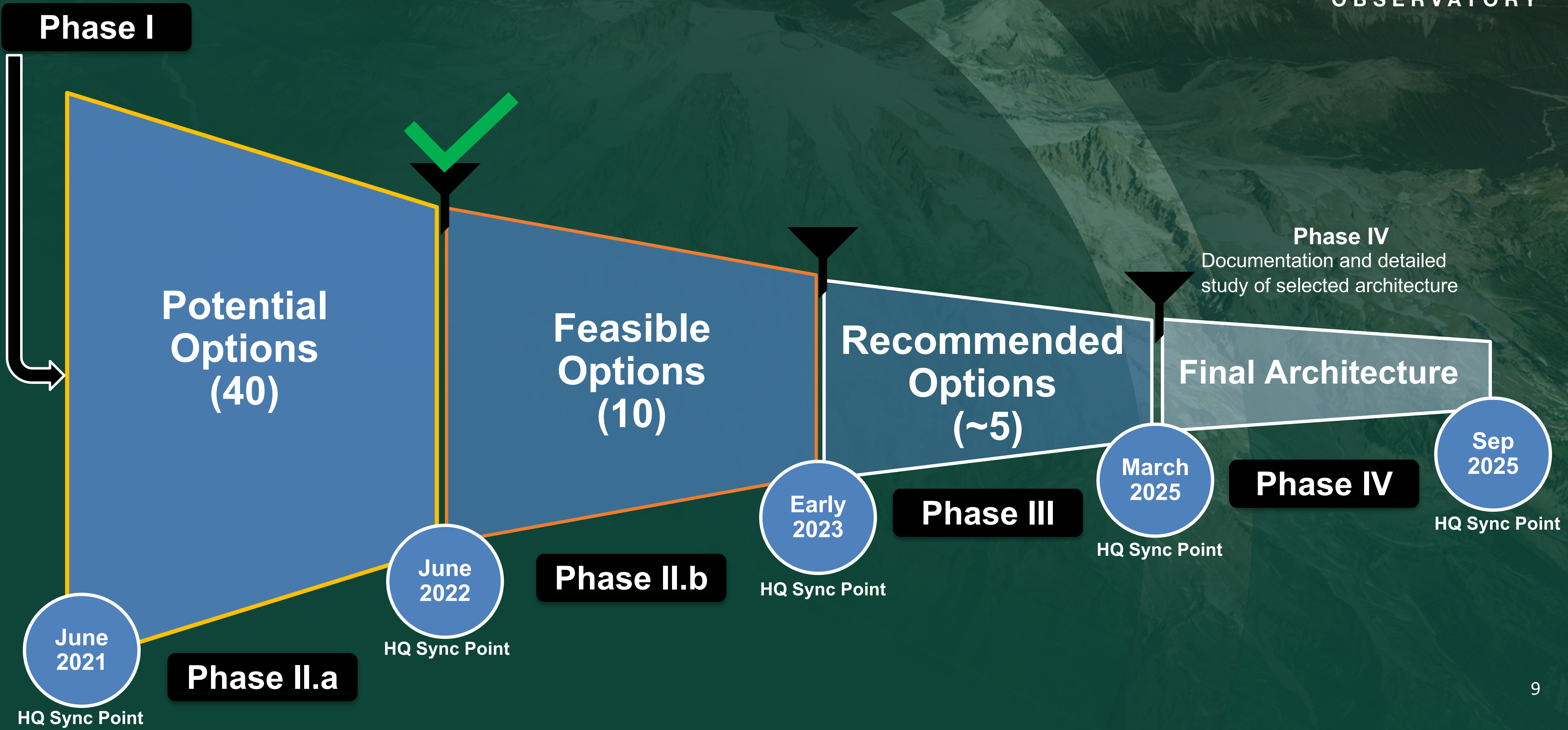

The SDC Value Framework

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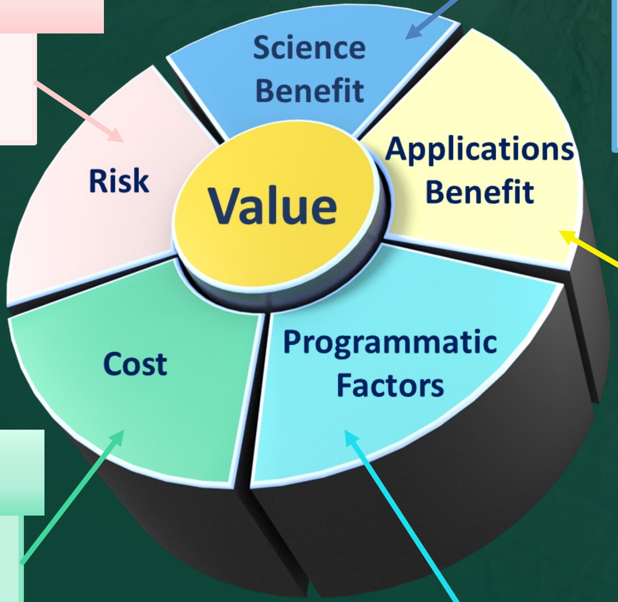
Study Leadership Architecture Team

- Architecture Group (e.g. single flagship) risks
- Individual Architecture risks

Research and Applications (R&A) Team Performance Tool Team

- **Feasibility** quantifies likelihood an architecture achieves Science performance targets for an Observable
- **Relevance** weights the utility of an Observable to a DS Goal
- **Benefit** is product of Feasibility and Relevance, aggregated at DS Goal level or higher



Research and Applications (R&A) Team Performance Tool Team

- **12 Communities and 26 Potential Enabled Applications mapped to Observables**

Study Leadership Architecture Team

- **NASA Instrument Cost Model**
- **Historical Analogues for Spacecraft**
- **NISAR-based operations estimates**

Study Leadership Architecture Team

- **14 Programmatic Factors defined by study leadership with HQ**

For each architecture under consideration:

- The assessment was performed consistently
- Objective assessments were prioritized
- Checks and balances were implemented
- All data sources were archived and linked to summary products

Benefits, cost, and risk are intentionally not rolled up into a single value score to avoid:

- Losing discriminators across architectures
- Combining uncertainty and different levels of fidelity in the assessments
- Anchoring cognitively on an initial value when the design process is iterative

Science Assessment Example

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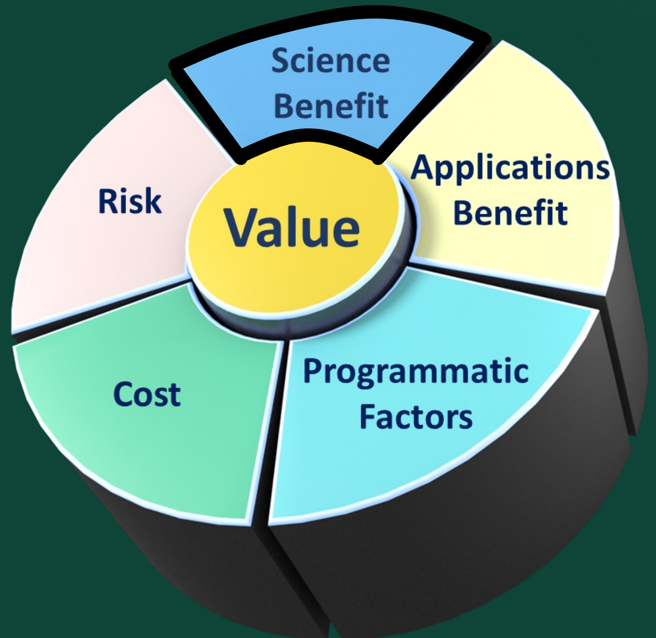
	Revisit	Accuracy	Coverage	Feasibility
Shallow aquifers (deformation) SATM	7 days	3 mm	100%	-
L4A Capability	3 days	4.4 mm	83%	-
L6C Capability	9.8 days	1.3 mm	72%	-
L4A Partial Feasibility	1.0	0.95	0.83	$\boxed{0.93}$
L6C Partial Feasibility	0.71	1.0	0.72	$\boxed{0.81}$

Aggregate across GOs



Science Benefit	L1A	L1C	L4A	L5A	L6C	L6E	L9A	L12B	L12C	L18A
Cryospheres	0.75	0.76	0.79	0.72	0.71	0.71	0.71	0.73	0.63	0.62
Ecosystems	0.86	0.84	0.90	0.82	0.78	0.78	0.78	0.85	0.50	0.50
Hydrology	0.85	0.85	0.91	0.85	0.82	0.82	0.80	0.82	0.75	0.75
Solid Earth	0.75	0.78	$\boxed{0.83}$	0.80	$\boxed{0.78}$	0.78	0.78	0.81	0.76	0.76
GeoHazards	0.67	0.68	0.74	0.87	0.59	0.59	0.74	0.71	0.96	0.68

Cost Assessment

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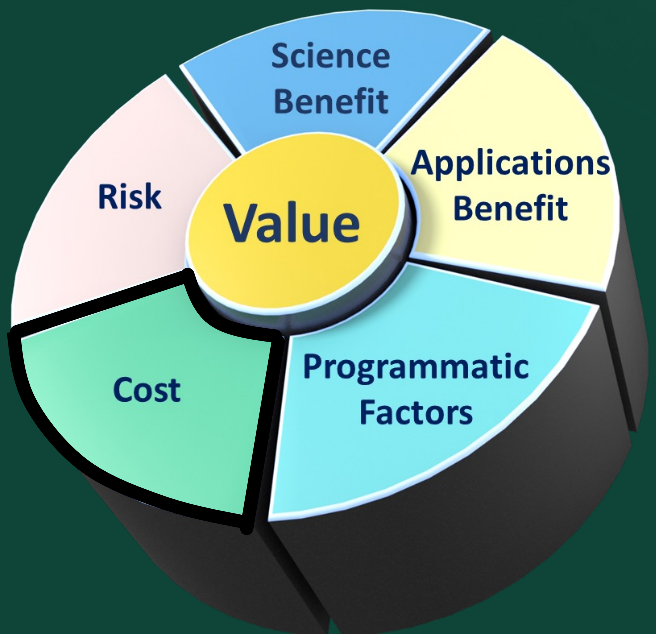
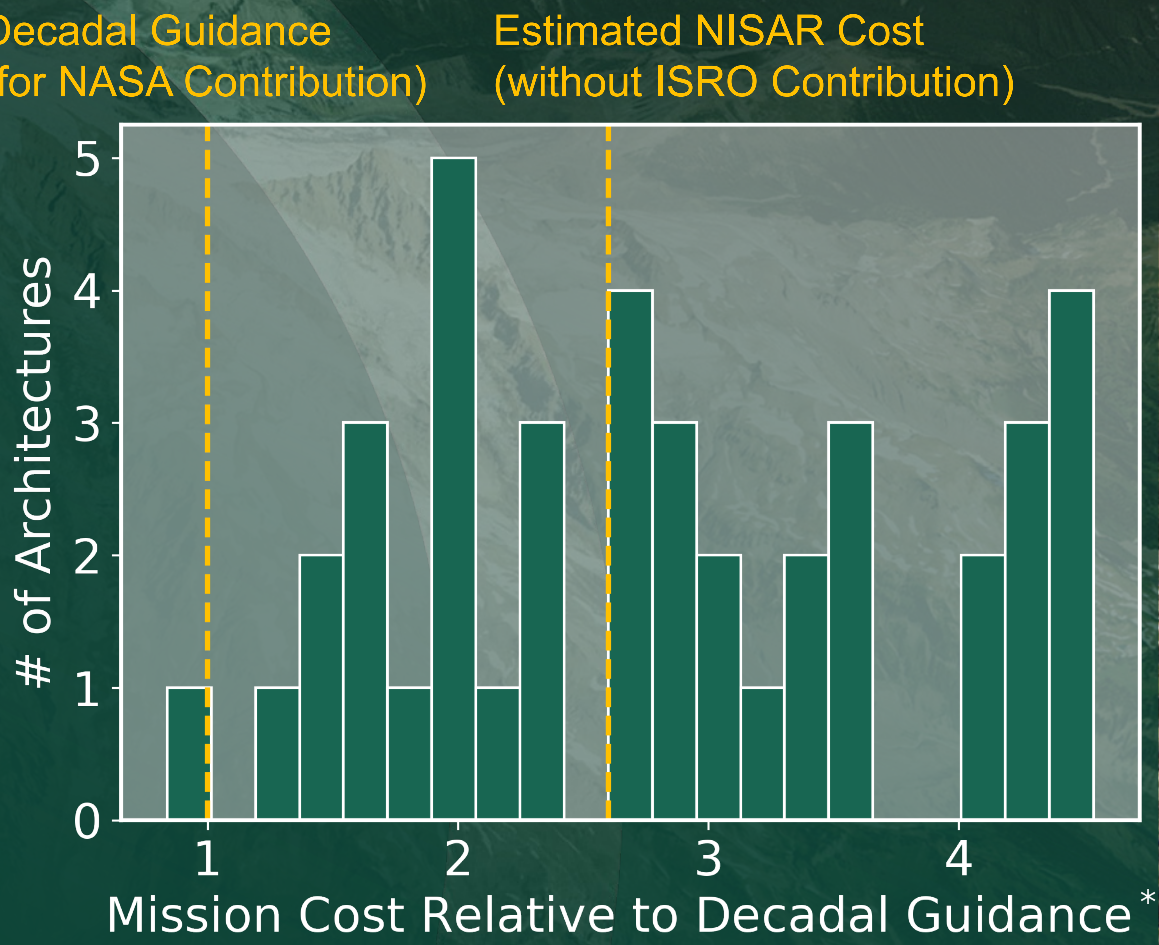
Cost estimates enable comparisons among architectures and point to ***potential opportunities for partnerships, technology development, and commercial SAR data*** to meet SDC objectives for maintaining continuity while enabling new science





* Cost estimation is for phase A-F and includes reserves. Assumes entirety of cost is borne by NASA using past analogy costs

Other Components of Value

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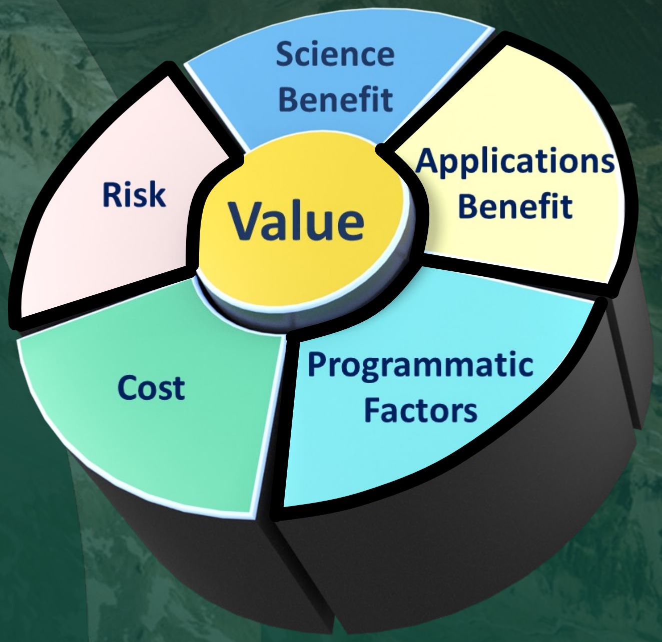
- ***Application Benefit*** is assessed for each of ***26 application areas*** and ***12 communities***

- ***Programmatic Factors*** characterize other benefits associated with each architecture, for example
  - ***Opportunity to leverage international participation***
  - ***Synergies with the other ESO missions***
  - ***Opportunity to leverage commercial data buys***

- Formulation risk assessments ***reduce uncertainty in the development of the architectures*** by identifying areas for further study



Downselect Process

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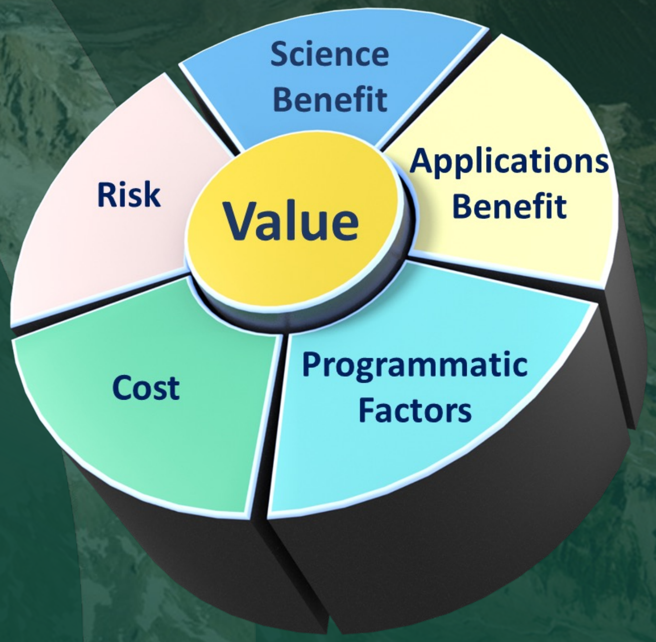
SDC Study Team reviewed assessments of all architectures and components of Value

⇩

Downselect committee individually developed initial disposition of architecture to Include, Maybe include, or Exclude

⇩

Committee used Value Framework products and Study Team analysis to create portfolio of architectures to carry into Phase II.b



Outcome of the Phase II.a Downselect

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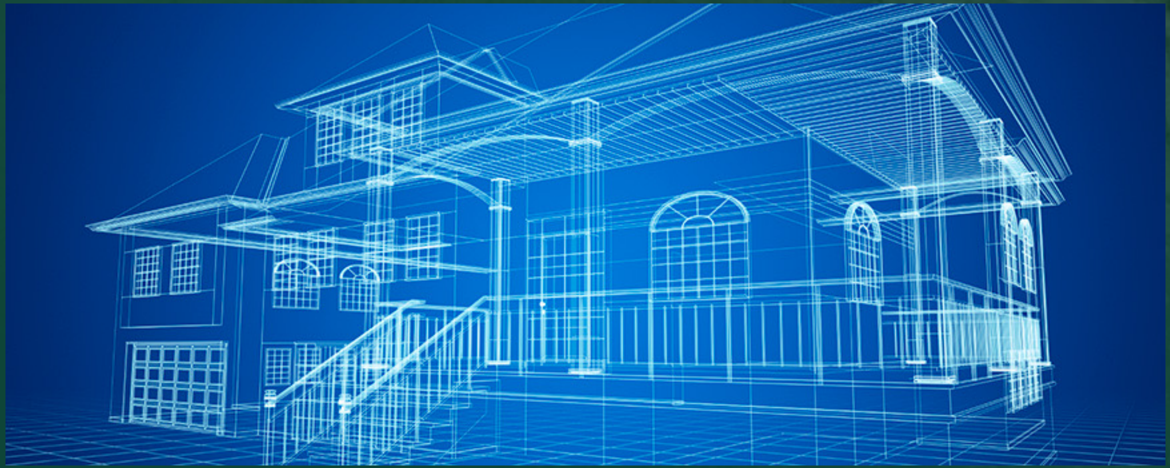
Architecture	Description
L1C*	NISAR-Lite with miniaturization tech investment and a DAR/DIAL instrument for water vapor estimation.
L4A	Building 2 NISAR-like instruments to complement the 2 ROSE-L instruments being proposed. Would fly 90 deg out of phase with ROSE-L in sentinel orbit.
L5A*	Five L-band satellites equally distributed around a 10-day repeat orbital plane and covering 1/4 NISAR swath. Mechanical steering can cover any 60 km swath with 2 day repeat. Significant overlap between adjacent beams.
L6C	Multi-squint co-flyers surrounding the ROSE-L zero-doppler instruments. ROSE-L will have capability to sync external. Co-flyers are active. Targets both 3D deformation and atmospheric removal.
L6E	Multi-squint co-flyers surrounding the ROSE-L zero-doppler instruments. ROSE-L will have capability to sync external. Co-flyers are passive. Targets both 3D deformation and atmospheric removal.
L9A*	Multi-squint formation covering 1/3 NISAR swath in NISAR orbit. Mechanical steering could convert from multi-squint to overlapping coverage to reduce repeat times.
L12B	Two groups of six satellites operating in helical orbit. Each satellite covers 1/6 NISAR swath steered to zero doppler with adjacent swaths. Alternate modes would perform STV and cross-along-track interferometry objectives.
L12C*	A constellation using low radiometric accuracy and low orbital duty cycle designed to lower the cost per spacecraft to the minimum
L18A	A constellation using low radiometric accuracy and low orbital duty cycle designed to lower the cost per spacecraft to the minimum. Grouped for 3D deformation. All 18 active instruments
L8A	Eight L-band satellites separated by 6 hours from each other in NISAR/close-to-NISAR orbital plane and covering 1/8 NISAR swath. Mechanical steering can cover any 30 km swath with 6 hours repeat.

Baseline: L1A

*Also study S-Band to understand impact of frequency

Surface Deformation and Change Architecture Study Overview



Architecture Lead: Shadi Oveisgharan[1]

Study Coordinator: Paul Rosen[1], Phase II Lead: Stephen Horst[1], Batu Osmanoglu[2]

Value Frame Work Lead: Chris Jones[3], Performance Tool: Katia Tymofyeyeva[1], Mission Plan: Adrien Maillard[1], Orbit Generation: Diana Illingsworth[3], Vianni Ricano Cadenas[3], SDC Team

1: Jet Propulsion Lab, 2: Goddard Space Flight Center, 3: Langley Research Center

Dec.13th 2022

Architectures Identified by Attributes

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The science community identified attributes that drive our architectural decisions

- **Continuity**: Likelihood of extending the current program of record beyond NISAR with overlap
- **Global Repeat Time**: Improving the time between interferometric repeat intervals globally
- **Local Repeat Time:** Improving the time between interferometric repeat intervals in targeted areas
- **Atmospheric Error Reduction**: Reducing measurement uncertainty via estimates of tropospheric delay
- **Look Diversity**: Improving deformation estimation in all 3 spatial dimensions to enable new science
- **STV Synergy:** Architectures providing synergy with the Surface Topography and Vegetation observable
- **Spatial Coverage**: The portion of the globe covered by the instrument in its repeat cycle
- **High Quality Backscatter**: The ability to produce useful backscatter data for science

Current SATM Attributes Requests for some of Geophysical Observables

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Geophysical Observables	Frequent* revisit	3D deformation	High* LOS accuracy
Volcanic Systems and Hazards	Requested	Requested	Requested
Earthquake Cycle and Hazards	Requested	Requested	Requested
Landslides Hazards	Requested	Requested	Requested
Rapid Deformation Map Acquisitions	Requested	Not Req.	Requested
Sea Level Rise, 3D Surface deformation vectors on ice sheets, Ice Velocity	Not Req.	Requested	Not Req.
Sea Level Rise, Vertical motion of land along coastlines	Requested	Requested	Requested
Landscape Change (reflectance)	Requested	Not Req.	Not Req.
Landscape Change (deformation)	Requested	Requested	Not Req.
Effect of convection	Not Req.	Requested	Not Req.
Groundwater flow	Requested	Requested	Not Req.
Groundwater fluxes	Requested	Requested	Requested
Shallow aquifers	Requested	Requested	Not Req.
Impact of human activities and water flow on earthquakes	Requested	Requested	Not Req.
Discovery/Management, Mapping energy, agriculture, and natural resources	Requested	Requested	Not Req.

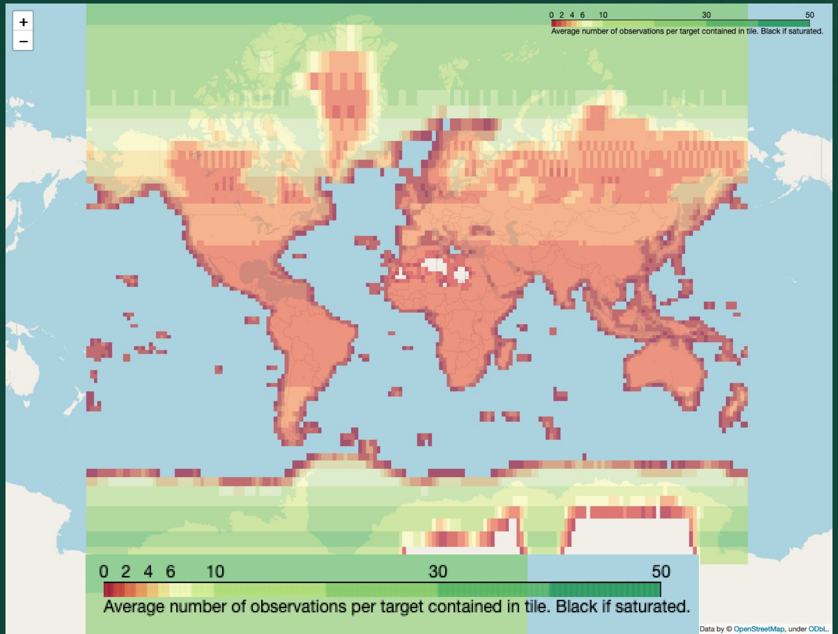
Legend: Requested | Not Req.

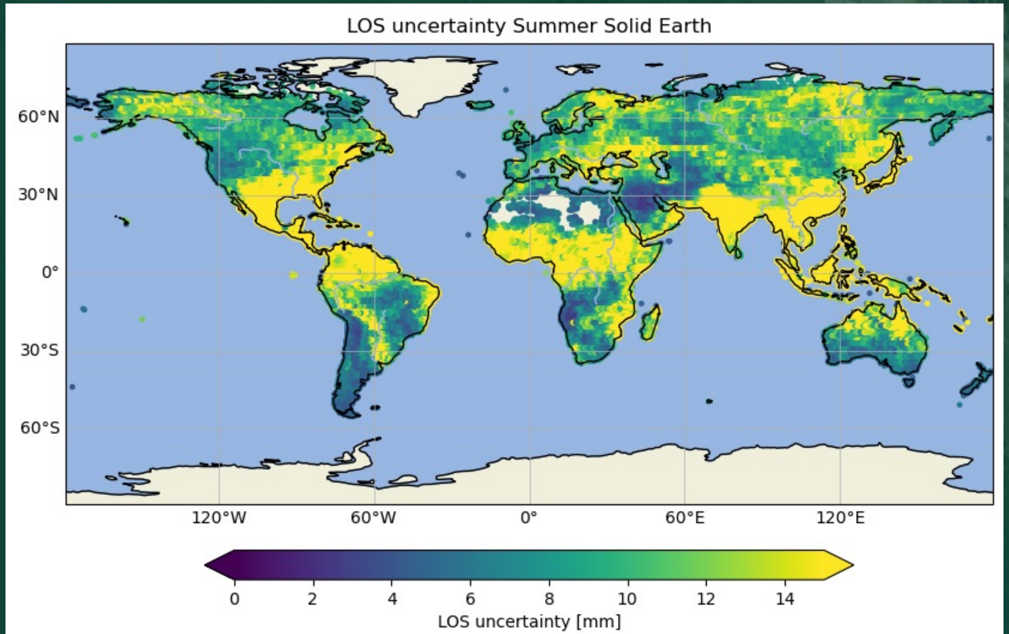
* Relative to NISAR

Continuity

- We have an architecture for that: (actually 7 out 10)
- Exemplar: NISAR-Lite (L1A)
    - It has direct 1-1 continuity for NISAR
    - Options for reducing cost: polarization, S-band, maximizing the usage of NISAR spare components

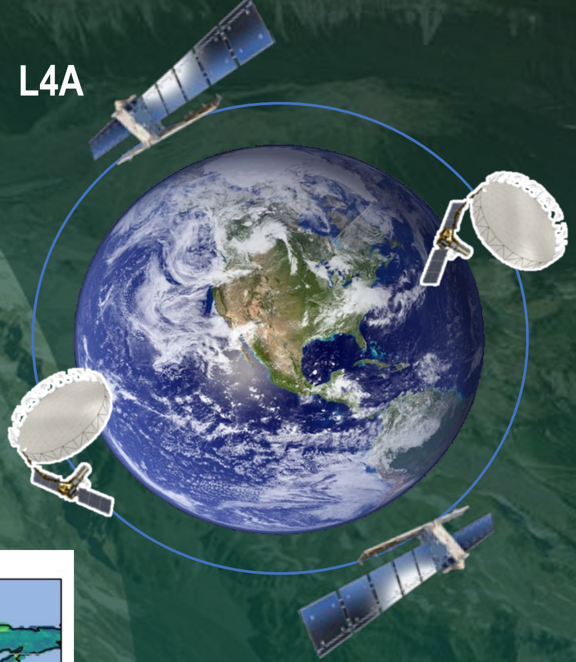
L1A

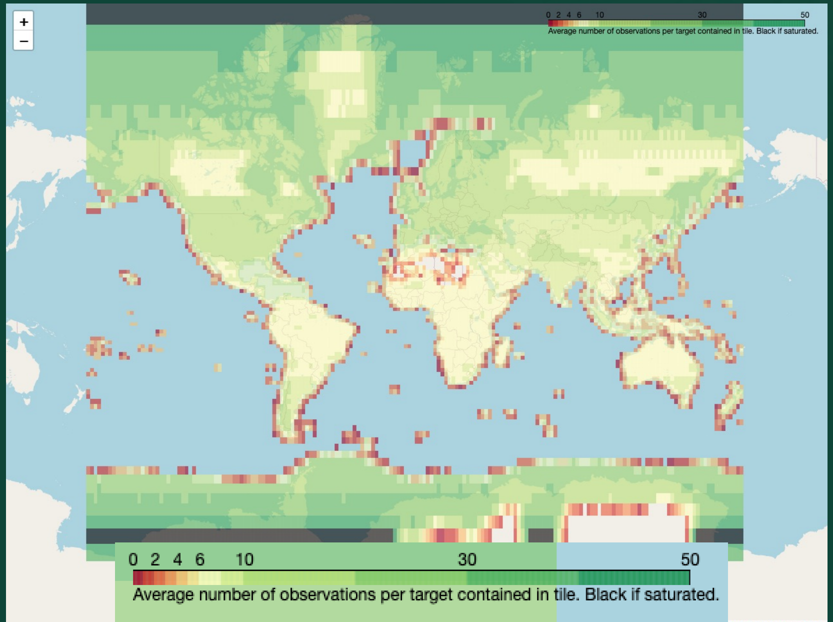


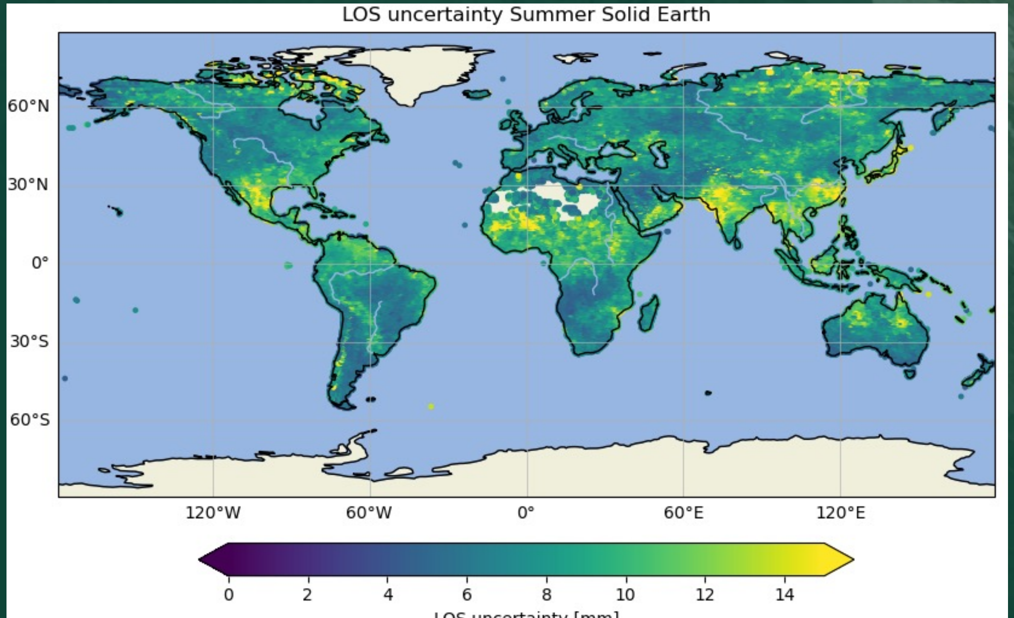


Fast Global Revisit Time

- We have an architecture for that: (actually 2 out 10)
- Exemplar: Two NISAR-Lite+ROSE-L (L4A)
  - Much better science accuracy compared to NISAR
  - Cost twice as NISAR
- The cost is proportional to improvement in global revisit time







Fast Local Revisit Time

Urgent Response

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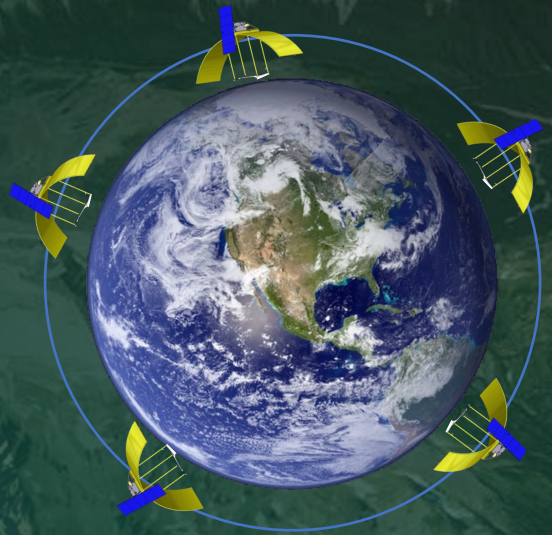
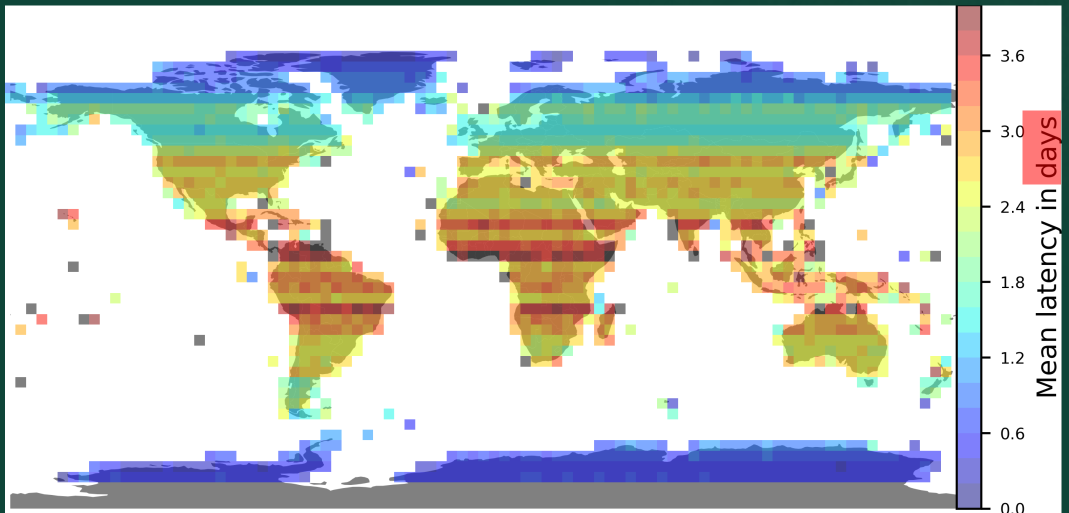
- We have an architecture for that: (actually 4 out 10)
- Exemplar: L5A
    - 5 equally distributed smaller satellites that cover 1/4 of the adjacent ground track swath
- The latency for this architecture decreases to **less than 18 hours** instead of **3-4 days for NISAR**.

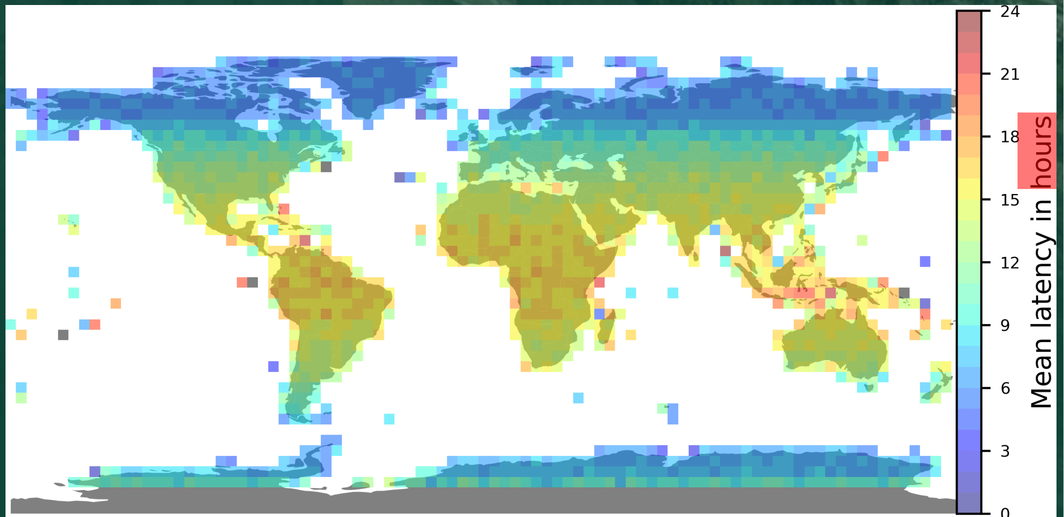
L5A



L1A



L5A



Fast **Local** Revisit Time

Targeted Area

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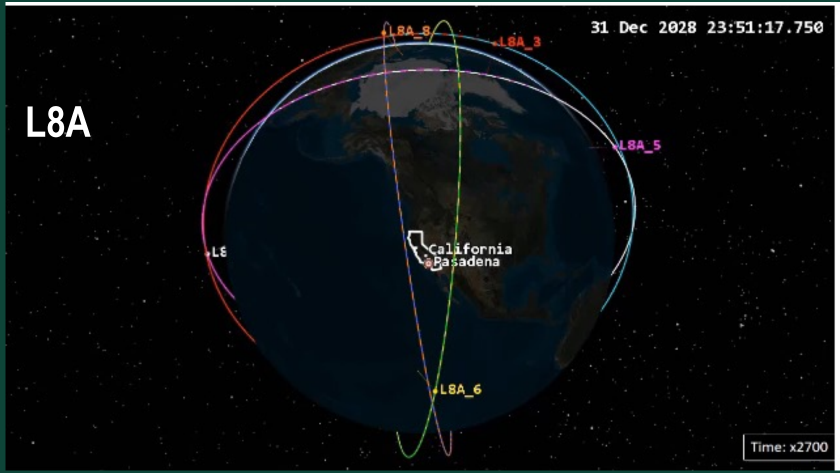
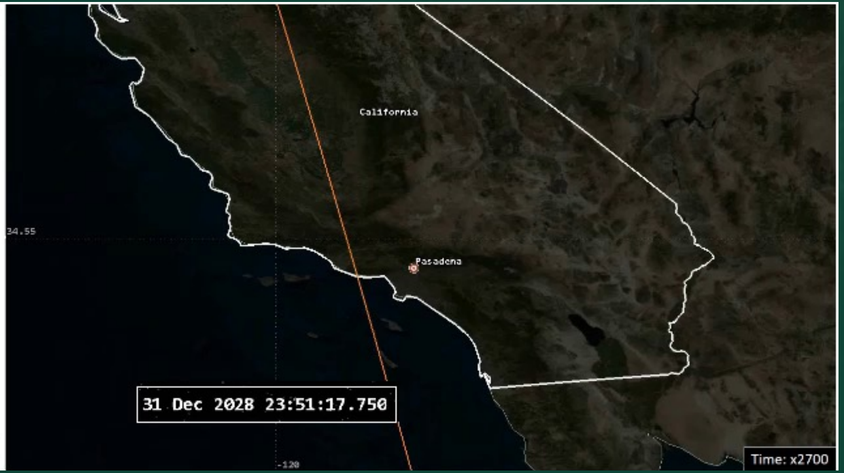
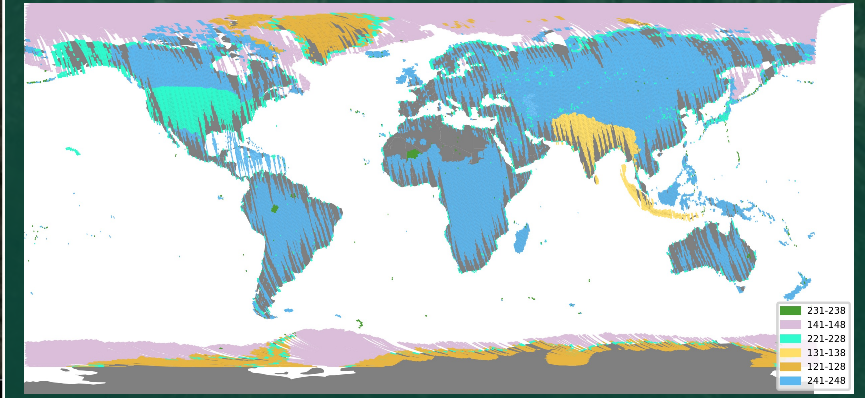
- We have an architecture for that (and no more)
- Exemplar: L8A
- Fast Temporal Sampling is needed for some processes to avoid aliasing of the deformation signal
  - Glacier flow subject to tidal forcing with 12 hour period -> 6 hour revisit
  - Soil moisture decays with days-long diffusion response, -> daily revisits
  - 8 SATM GOs requested 6 hours revisit time, mainly in coastal regions
- Revisit time over **coastal regions** is **6 hours for 2 days in 12 days**
- **Global** Revisit time is **12 days**
- To avoid big holes, we need electronic steering
- Note: Revisit time for **urgent response** is between **6 hours to 10 days**







Fast Local Revisit Time

Regional

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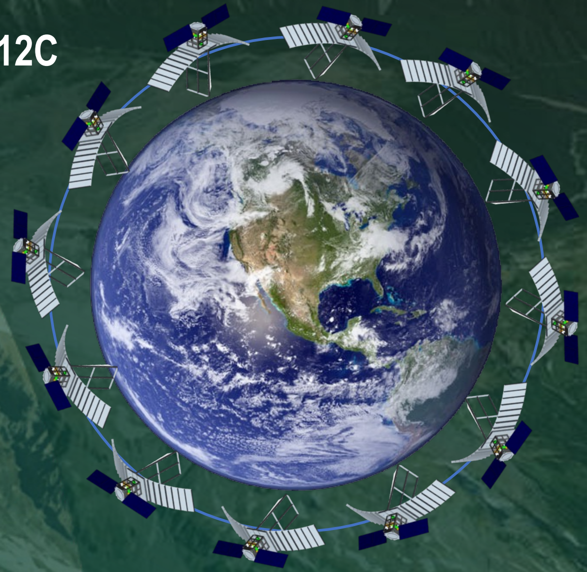
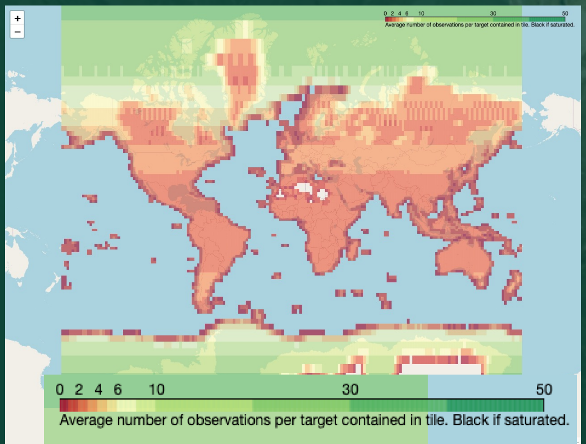
- We have an architecture for that (and no more)
- Exemplar: L12C
    - low duty cycle (15% compare to 50% NISAR)
- low SNR (-15dB) and single polarization
    - not useful for applications such as soil moisture and biomass estimation.
- systematic faster revisit time over a region such as US/Alaska
- A good representation of future commercial architecture

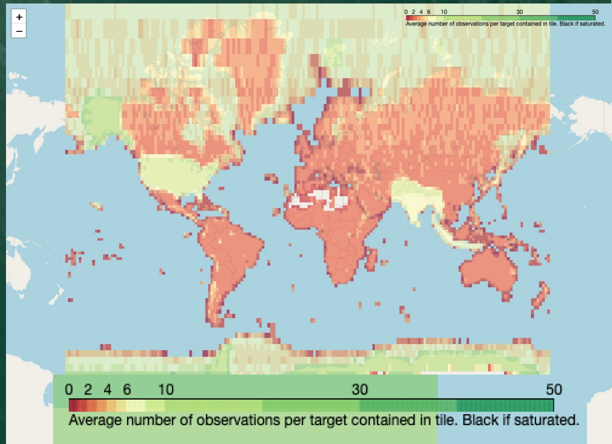
L12C



L1A

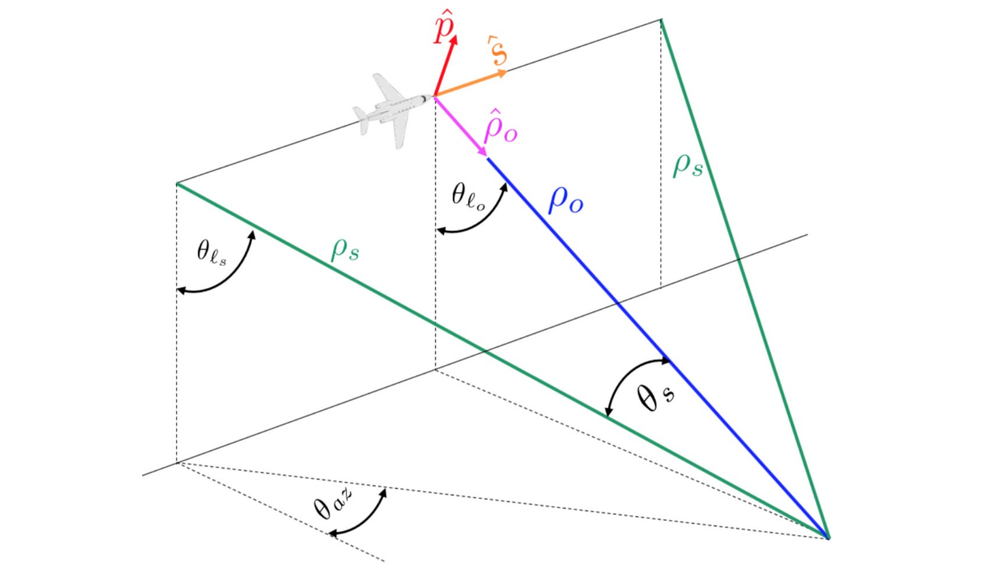


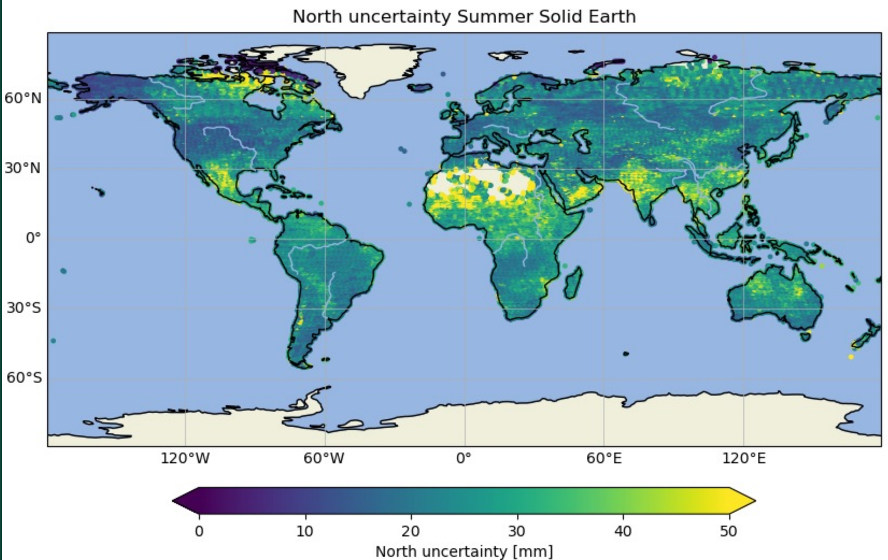
L12C

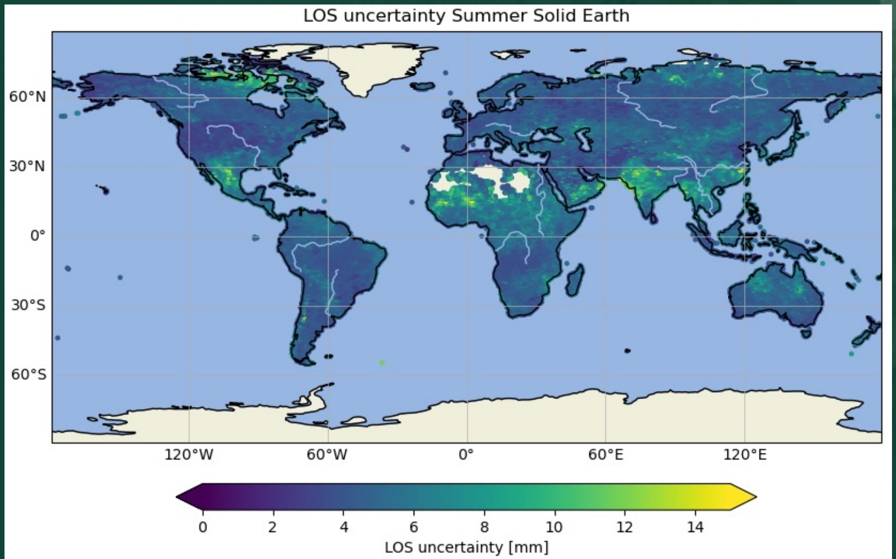


Atmospheric Error Reduction + Look Diversity

- We have an architecture for that: (actually 4 out 10)
- Exemplar: ROSE-L with 4 co-flyers (L6C)
- Multiple real-time look angles enable
  - accurate **removal of atmospheric** noise
  - good estimation of all **3 spatial** components
- Enables **new science** at the expense of coverage density
- Alternatives to multi-squint geometries for removing water vapor is Differential Absorption Radar (DAR) at millimeter wave frequencies







Synergy with other Measurement Concepts
Surface Topography and Vegetation Incubator

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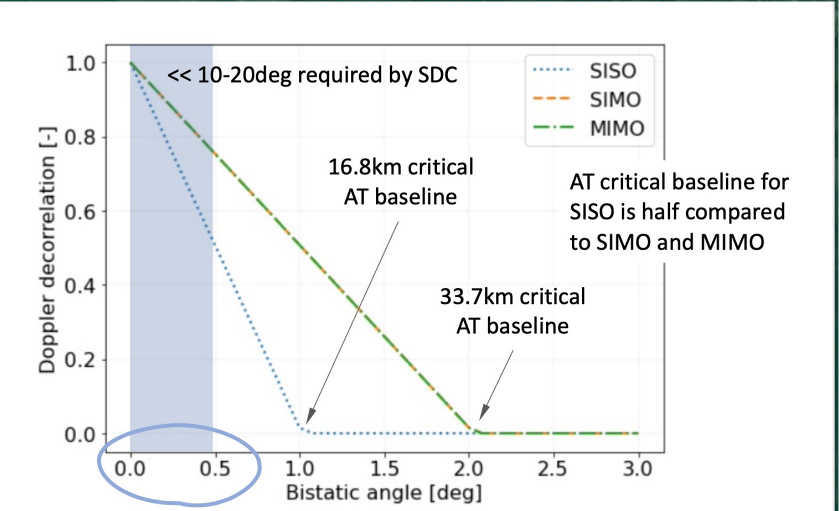
- We have an architecture for that: (and no more)
- Exemplar: Multiple spacecraft in a helical orbit (similar to TanDEM-X) (L6D)
- SDC and STV need to share measurement time
    - STV requires along track baseline less than 10km (1 degree bistatic angle) [Lavalle et al, 2022]
    - SDC requires along track baseline of around 250km (20 degrees) in squinted geometry

From DARTS project (ESTO IIP; PI: M. Lavalle)

DARTS

Distributed Aperture Radar Tomographic Sensors



Lavalle et al, ESA LPS 2022

Selected Architectures

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Architecture	Architecture Characteristic	Orbital Groups	Pol.	Per Satellite Swath (km)	Global Revisit Time (Days)	Local Revisit Time (Days)	Science Characteristic	Relative Cost
L1C	NISAR w/PWV inst.	1	Quad	240.0	12	12		2.9
L4A	2x NISAR w/Rose-L	4	Quad	240.0	3	3		3.6
L5A	NISAR via 5 Small Sats.	5	Dual	60.0	8	2		1.6
L6C	Rose-L Active Multi-Squint Co-fliers	2	Single	80.0*	6	6		1.0
L6E	Rose-L Passive Multi-Squint Co-fliers	2	Dual	80.0*	12	6		2.0
L8E	Sub-Daily Repeat for targeted area in 12 days	1	Dual	40.0	12	0.25		2.1
L9A	NISAR via Multi-Squint Co-fliers	3	Dual	80.0	12	4		2.4
L12B	Multi-Baseline Helical Orbit	2	Dual	40.0	6	6		2.3
L12C	Fast Revisit Low Cost per Sat.	12	Single	60.0	12	1 3		1.8
L18A	Multi-Squint Low Cost per Sat.	6	Single	60.0	12	3		2.2

*Reported swath is for the co-fliers, not Rose-L.

Urgent Response

Targeted Area

Regional

Improved single observation accuracy using phase

Reduced single observation accuracy using amplitude

3D Vector Deformation

Tomography for Veg. structure

Science Community Feedback
Atmospheric Error Reduction + Look Diversity

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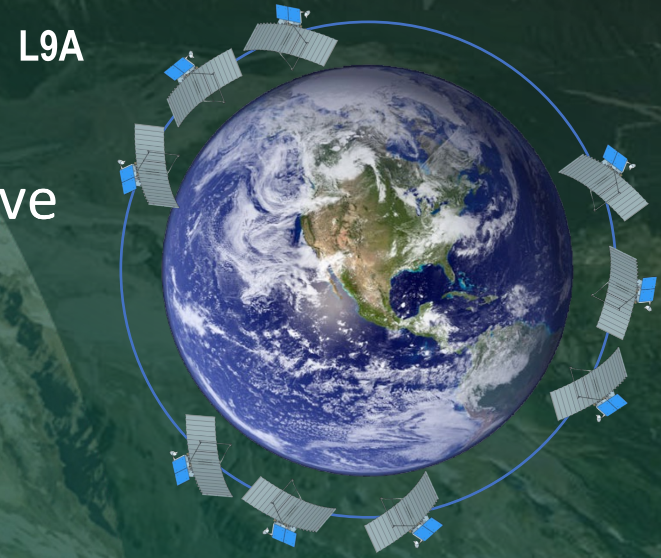
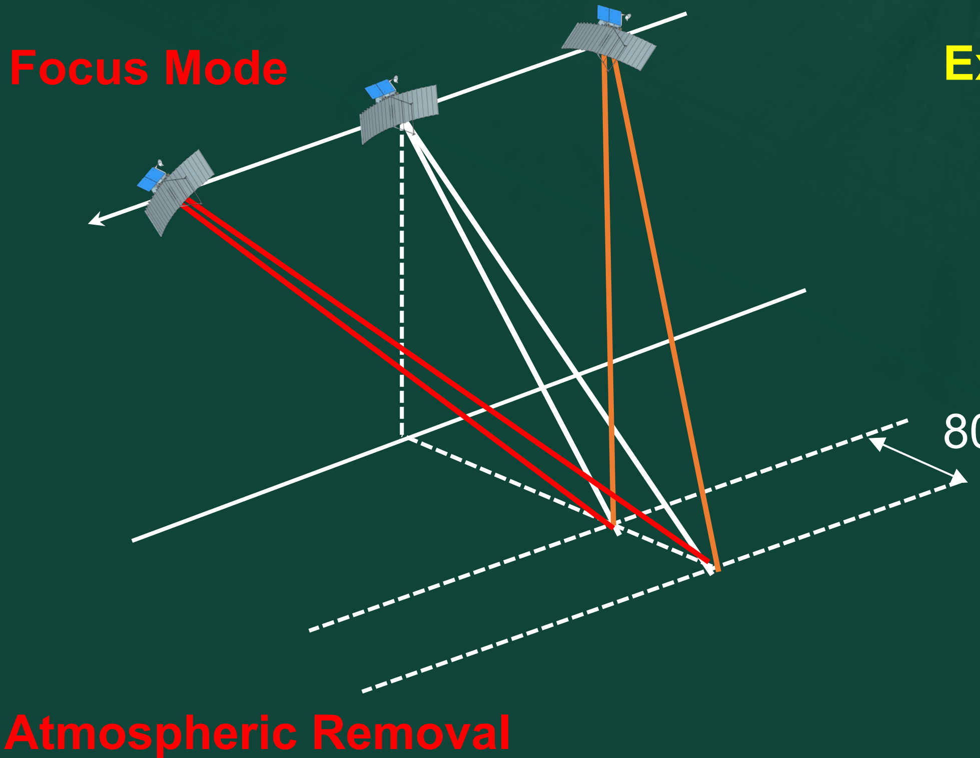
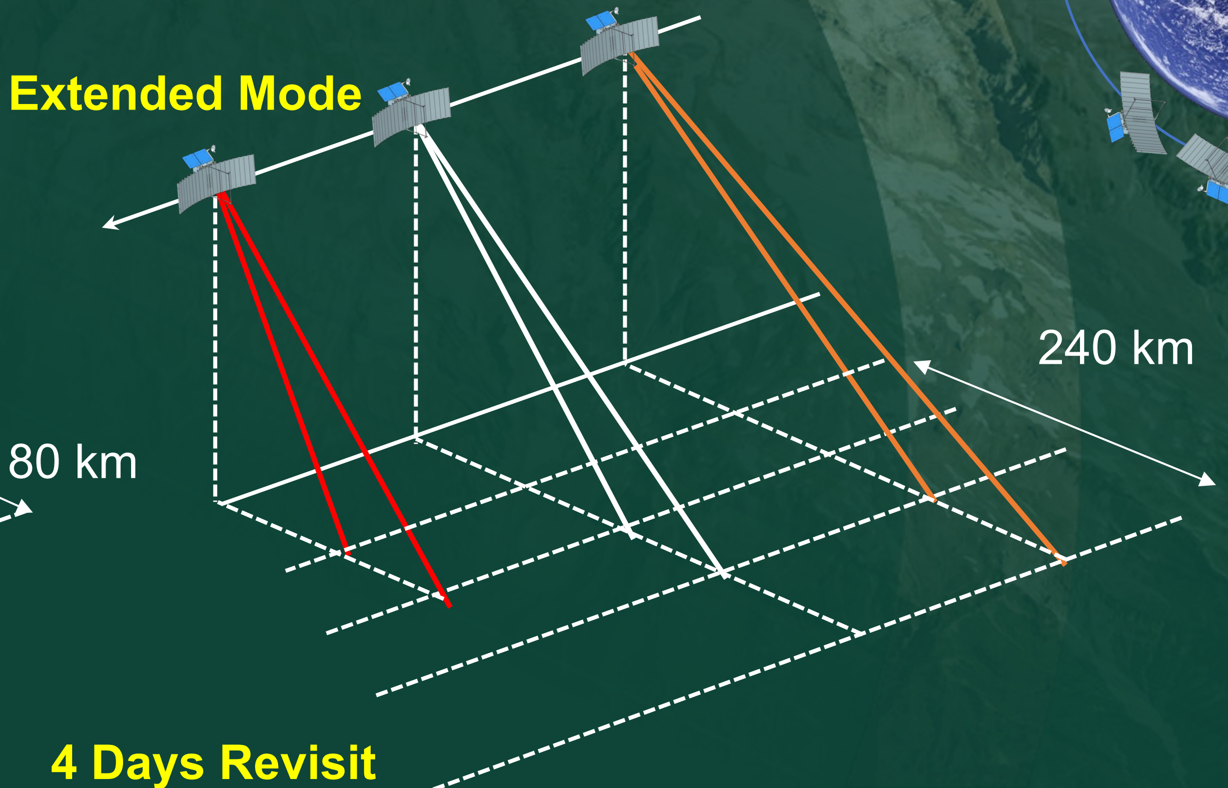


Science Focus Group Inputs to be collected:

- Identify regions (spatially and temporally) that you prefer to have **4 days** revisit observations instead of **atmospheric removal**





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SDC represents NASA's commitment to SAR data

Help us to maximize the value of that data for your science and applications needs!

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  sdc-study@lists.nasa.gov

- Check out our website!

  https://science.nasa.gov/earth-science/decadal-sdc

- Check out our SATM with focus areas on:
  - Solid Earth / Geohazards
  - Cryosphere
  - Hydrology
  - Ecosystems

Learn more about our candidate mission architectures!